

WATER INFRASTRUCTURE MAINTENANCE REPORTING PROCEDURES: A STRUCTURED FRAMEWORK TO REDUCE NON-REVENUE WATER (NRW) DISCHARGE

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Monetary losses from current inefficient reporting mechanisms related to non-revenue-water (NRW) discharge is a global problem. This project-work's solution is a newly developed deliverable that addresses a main objective to develop a structured flowchart for improved asset management of water infrastructure; where, NRW is the volume of water that is put in the distribution system but is not billed and does not add revenue. A qualitative research methodology was applied, with structured interviews conducted with six key respondents actively involved in the operation and maintenance of water infrastructure, within a Kenyan case-study. The challenges currently faced in reducing NRW levels are made explicit. Findings are presented that, newly developing regions' procurement malpractice potential, can be addressed with application of a structured life-cycle-costing approach able to flag poor quality materials over a facility's explicitly measured utilization period. This work finds that significant improvements can be realized for O&M via a suggested, instigated in-house engineering technical application, and that such an initiative can be embedded into a developed flowchart that outlines procedures to improve the operational efficiency of both new and existing assets.

Keywords: Water resources, Managing, Controlling, Water distribution, LCCA.

1 INTRODUCTION

Non-revenue-water (NRW) discharge is a global problem; such water is outside distribution systems and is thus not billed nor able to add revenue to public (and increasingly private) utility-boards (WASREB 2014). The world bank estimates that 32billion m³ of water is lost every year. High-capacity economies are as liable to the vagaries of NRW as lower-GDP regions. Ireland's ongoing infrastructure upgrades seek to address historical asset leakages of 40%; however, newly developing countries are most affected and experience half of all estimated global losses; Asean regional yearly losses are pegged at between 9-29 billion m³ where water-utility boards experience large resultant treatment and pumping deficits, with knock-on reductions of clean water for 150million+ residents (Kingdom *et al.* 2006, Frauendorfer and Liemberger 2010)

The IMF (2015) found that ten years ago, many African countries were still dependent on infrastructure installed during colonial periods. Countries such as Kenya, recognizing the need for action, sought a structured devolution of water services provision and instigated county-by-county water-services-provision (WSP) to address national annual losses of up to 9 billion shillings (USD70m) accounting for almost 7% of Kenyan-GDP (WASREB 2014). To reduce the levels of NRW, asset-management of water facilities requires ongoing attention.

1.1 Asset Managements

Asset management balances the costs of operating and maintaining (O&M) an asset, with a facility's performance outputs (The Water Research Foundation 2020). Asset management seeks to address daily operational procedures and respective strategic decision-making, with O&M budgets of water systems going towards the effectiveness and sustainability of the network; indeed, poor O&M across water infrastructure is the leading cause of NRW and hinders economic growth in many countries (Barreto Dillon 2009). Whilst some, somewhat skeptically, suggest that often there is a build/ neglect/ rehabilitate cycle mentality at play, where assets deteriorate over time without structured rehabilitation (Tran *et al.* 2023), most find that O&M is categorized into the three main categories of preventative, corrective and reactive maintenance.

One tool to assist with asset-management is life-cycle cost analysis (LCCA), which itemizes all costs incurred during ownership of the asset, from design, manufacturing, utilization of the asset, operation and maintenance costs and residual costs associated with disposal of the asset (Tan and Whyte 2023). Organizations that apply LCC, experience benefits such as positive decision making of long-term investments and selection of elemental specifications. An asset inventory of the status of existing water infrastructure is a first step in implementing LCCA (Ira 2017, Veenkant and Fonseca 2019). Accurate estimation of the life of the pipes making up the network plus their failure rates, replacement and repair costs during each stage are essential aspects of LCCA, where cost calculation that can be predicted as a function of: cost related to installation, repair, leakage, replacement of the pipes, pumping costs and hydraulic efficiency, corrosion cost, and customer service rebates and penalties due to failures (Ambrose *et al.* 2008). Application of LCCA in the planning and operation of water infrastructure can lead to a great reduction in NRW.

2 QUALITATIVE METHODOLOGY

Qualitative research methodology deals with the collection and analysis of experience or opinions of expert practitioners (USC 2011, Bhandari 2020). Notably for this study, data generated shall seek to assess asset-management practices related to non-revenue water occurrences in Kenya, via six semi-structured interviews with expert-engineers working in that water-sector. The analyses of these six participants' responses are deemed to be compliant with Creswell and Creswell's (2018) expectation for a life-experiences' quorum. This study's objectives can be stated as seeking an: (i)overview of asset management practices; (ii)LCCA application of water infrastructure in Kenya; (iii)assessment of Kenyan operation and maintenance practices of water infrastructure; (iv)determination of monitoring and leakage-detection of pipelines; (v)analysis of reporting-procedures related to illegal water connections; and, (vi)development of a structured flowchart as a guidance tool towards improved asset management of water infrastructure.

3 DISCUSSION OF RESULTS

The data-set findings are discussed below in terms of the themes arising, namely: asset ownership; training; departmentalization; user-illegality; and asset access-enforcement.

- *Asset ownership:* Upon completion of a water infrastructure project, the asset/facility is handed over to the water service provider whose jurisdiction falls within the project location. According to the respondents, there are cases where county-utility-boards have overlapping jurisdiction and do not know what boundary-assets belong to them, nor their specific locations. Manual records are somewhat ad-hoc and now need softcopy cross-reference towards date of asset acquisition; maintenance history; asset cost and current valuation; expected life of the asset; inspection frequency; risk rating and performance

- information; and location (through GIS).
- *Training and culture*: Interdisciplinary coordination between different departments on day-to-day activities is needed; respondents recommend that maintenance-engineers should take an operational leadership-role (rather than the current system where procurement/tendering departments enact periodic maintenance via sub-contractor negotiated awards). Respondents suggest that training to align LCCA and field-maintenance should occur, alongside increased awareness of obligations (and technical solutions) to address a culture of water-theft by consumers.
 - *WSP Measures to Reducing NRW*: Respondents call for an establishment of engineering-departments whose mandate is to oversee non-revenue water reduction, that encompasses both pipe-materials' upgrades that lessen easy-illegal access, and policing patrols of the major lines that are most prone to experience illegal tapping. Modern technologies implementation such as smart meters and leakage detection tools, sealing of meters to prevent tampering, and for large consumers, frequent monitoring of consumption near to main pipelines, are suggested as solutions. Crackdowns on illegal consumers, via heavy fines for tampering with the network, are suggested.
 - *Stakeholder engagement*: Sensitization-workshops, where the community is briefed on the benefits of non-revenue water reduction, is suggested here by the respondents; alongside a WSP national umbrella of water and sanitation service providers authority able to benchmark best-practice.
 - *Adequate funding*: Respondents suggest a reallocation of funds towards greater in-house technical maintenance expertise, rather than current allocations to external procurement departments to periodically enact repair projects. Funding such in-house training is suggested.

4 CONCLUSIONS AND KEY OBSERVATIONS

Conclusions are summarized below within two themes: asset-policy; and operational-strategies:

- *Asset Policy Development*: Respondents argue that current WSPs operate without an asset policy, and that, this is needed to ensure conformance to the specified pipe/etc. regulations. Asset planning through demand forecasting is sought by respondents, who argue for a targeted level of service based on empirical calculations of water-demand to determine which areas need larger diameter pipes or storage facilities. Maintaining reliable and integrated asset records are requested by respondents such that WSPs will be able to rank their assets based on their level of utilization and risk if defect occurs. Such records will direct procurement department to reorder materials and resources related to installation in a structured way.
Respondents call for an asset policy where maintenance and replacement of assets is based on life cycle costing analyses, and conditional monitoring of the asset, and an actual empirical risk assessment and related mitigation strategy. Pipes, valves and infrastructure approaching their end of life can then be flagged and replaced early before they fail or can be reused based on assessment by an in-house engineering department, with periodic inspections of high-risk assets increased. Such an asset policy will ensure there is clear accountability in the asset acquisition from funding source to supplier qualifications towards reducing the opportunity of malpractice in procurement.
- *Operational Strategies*: Secondary research shows the significance of the effects non-revenue water on utilities' performance. The respondents questioned here, argue that, reducing asset wastage can be addressed by ensuring all assets are fully integrated; for

example, pumping should not continue where pipelines record large leaks, and minor leaks necessitate reduce pressure. WSP engineers should be empowered to control assets' overuse; where one pump is working for extremely long hours, secondary pump installation should not require excessive decision-making.

Emergency plans should be in place in the event of a leakage or burst pipes. Respondents argue that WSPs should facilitate simple toll-free national hotline e.g., 990 or 100 to serve the entire country with citizens educated on how to report leakages or cases of tampering through digital or print media; hotlines should further direct the complaint to the specific WSP responsible. WSPs should work with community elders to liaise with (to be instigated) in-house experts able to address water infrastructure issues in a structured way: main valves serving the region should be clearly located with trained personnel enacting shutdown procedures in case of major pipe bursts.

New technology methods including the use of mapping software such as GIS and flow detection technologies on main distribution lines are argued by the respondents are required to determine leakages. Smart-meters' billing-systems and asset-monitoring-registers are called for, to ensure WSPs do not lose-out-on revenue WSP engineers should be directly involved in the design and construction of infrastructure projects which are being conducted by third party contractors.

Such input, it is argued by the respondents to this study, will be vital in ensuring that projects meet exact requirements and that assumptions made during the design and build process, target areas where measurement and monitoring mechanisms, post certificate-of-completion, are handed back to the WSP via structured, facilities-management approaches, that embrace: predominately routine maintenance where adjustments or cleaning or routine repair of the assets ensure optimum performance levels; ad hoc maintenance for sudden failures, e.g., for a burst pipeline or broken valve in a nominal way to supplement routine measures; and, reported maintenance mechanisms that respond to a leak or failure as reported to the WSP via (to be instigated) multi-media outlets.

5 RECOMMENDATIONS

Adoption of the above recommendations, populated by the responses received by this research project, can be argued to go towards an improvement in asset management practices by this case-studies' WSPs which can be further argued to lead to a reduction in non-revenue water levels. This study has addressed the six objectives stated above towards culmination of a newly developed structured flowchart tool; albeit final/ full validation of the logic flow-chart below remains pending.

The flow-chart below (Figure 1) has been developed from the primary research responses of the interviewees of this work, to supplement this work's literature-review secondary-research.

The figure below depicting an existing asset's 'Logic Flow-Chart for Best Practice Procedures in Water Network Infrastructure' highlights the procedure of acquisition beyond new asset design, procurement and construction, after it is handed over to the WSP. After which, it will follow the maintenance procedure for existing infrastructure directed in the stage-by-stage incidents' reporting and directed mitigation strategies.

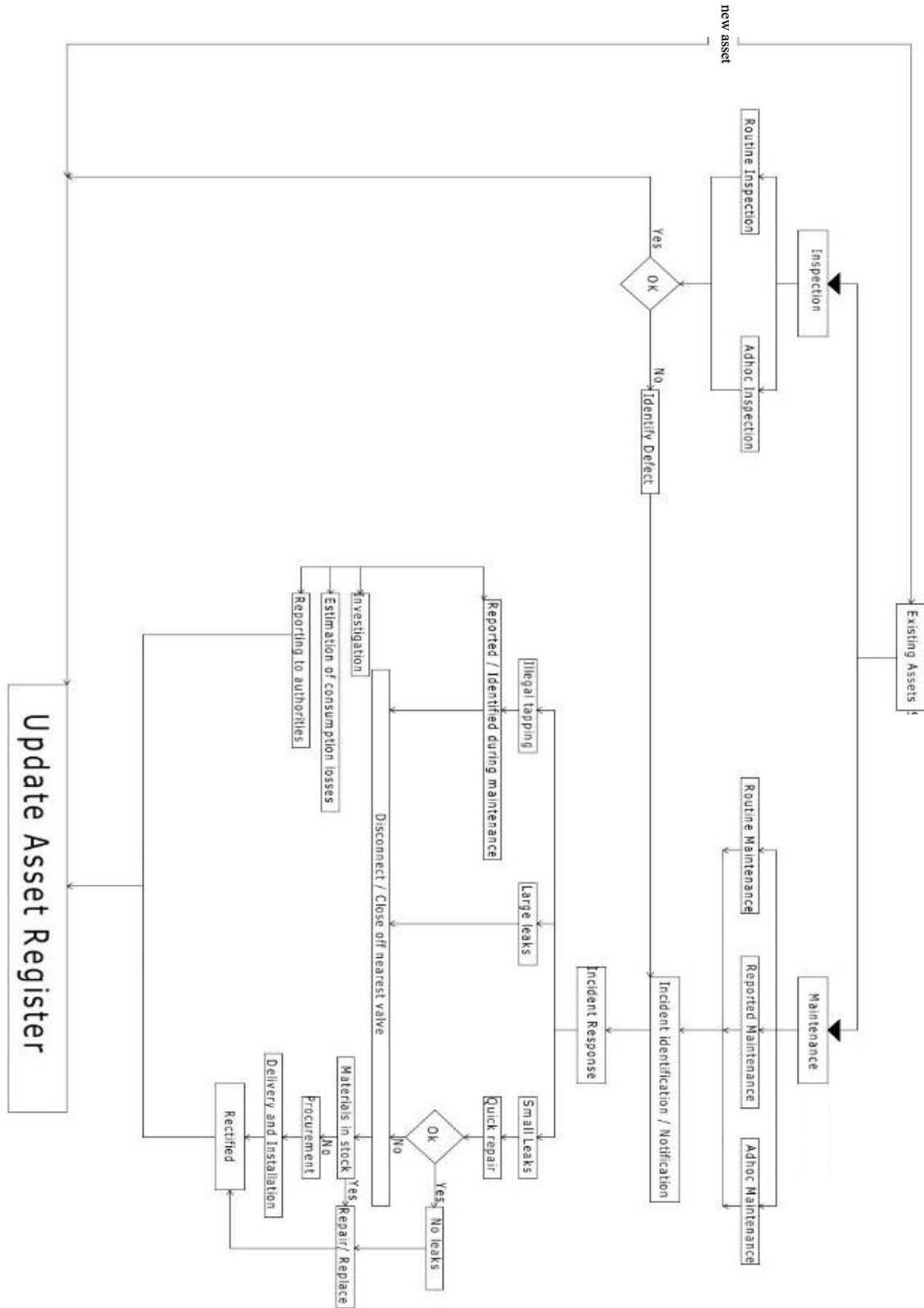


Figure 1. Logic flow-chart for existing-asset best practice procedures in water network infrastructure.

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